RESEARCH DEPARTMENT

Examination of the Distribution with Frequency and Time of the Field of WWV at Tatsfield during Six Months near the Sunspot Minimum

Report No. K.097

Serial No. 1954/17

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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1. SUMMARY.

Hourly measurements of the field of WWV on 5, 10, 15 and 20 Mc/s have been made at Tatsfield over the greater part of the day for the last six months of 1953, and these have been analysed. The departure and arrival angles corresponding to the different propagation modes for the different frequencies, times of day and seasons were estimated. The measurements were then corrected for the vertical patterns of the aerials, and, having regard to the different powers fed to the aerials on different frequencies, reduced to a constant transmitted power of 1 kW, and expressed in decibels referred to 1 μV/m. The distribution of the field was then plotted for each month on a frequency/time scale, in contours of the monthly mean of the mean-peak field. These are given in Figs. 3 to 8, which also show the predicted MUF and LUF for each month, for comparison.

The contours show that the field is distributed, with frequency and with time, somewhat as the MUF and LUF predictions indicate. Highest fields occur, however, where multiple modes of propagation are possible, which is on frequencies well below the actual MUF, provided that the absorption is low. Thus much stronger fields occur at night than during the day, and stronger fields during the winter day than during the summer day. Strong fields occur on much higher frequencies during the winter than during the summer day, because of the winter daytime increase in F_2 layer ionisation but, at the same time, the field is also stronger on the lower frequencies during the winter than during the summer day, because of the decrease in absorption. The predicted MUF's tend to be low in frequency during certain times of day and season, though the strongest fields usually occur below them. The loss of field due to absorption occurs earlier in the day than is indicated by the predicted LUF's, but, in the evening, strong fields are obtained below the predicted LUF's.

2. INTRODUCTION.

Towards the end of June 1953 a programme of hourly field-strength measurements was started at Tatsfield upon the signals received from the Standard Frequency station WWV of the National Bureau of Standards at Washington, D.C., U.S.A. The Tatsfield measurements were continued until the end of December, 1953.

The aim of the measurement programme was to study the diurnal and seasonal variations in propagation conditions over the important Trans-Atlantic transmission path, in this case the transmission path from Washington to Tatsfield. The measurements were made at hourly intervals during the greater part of the day upon the fixed frequencies of 5, 10, 15 and 20 Mc/s, upon which WWV continuously transmits. The reason for selecting the signals of WWV upon which to make the measurements was that only a station such as this will transmit continuously upon fixed frequencies irrespective of time of day or season. From these measurements it was hoped to obtain, by interpolation, a complete picture of the distribution of the field with frequency and with time of day at Tatsfield, averaged for each month. This would enable the diurnal and seasonal variations in the field due to the changing propagation conditions to be studied, and the reasons for the variations in the field with frequency to be assessed. By continuing the measurements for six months a complete seasonal change in propagation conditions was covered, since conditions during each month during the first half of the year would be similar to those during a corresponding month during the second half. Since the measurements were made over a complete seasonal change near the sunspot minimum period it was felt that they might be useful during several years around that period, when conditions do not change very markedly due to the sunspot cycle. A secondary aim in making the measurements was to compare the diurnal and seasonal variations in field-strength with the predictions of MUF as obtained from the monthly world charts supplied by the Department of Scientific and Industrial Research, and with the predictions of LUF as obtained by the use of the American Central Radio Propagation Laboratory method of LUF calculation, and so to check the accuracy of these predictions. Both of these predictions are regularly used by the B.B.C. in the selection of the frequencies for use over the Trans-Atlantic circuit, as well as in the selection of those for use over numerous other B.B.C. circuits. It was hoped also that the frequency/time contours of equal field might be of direct use in assessing the incident field on either side of the Atlantic from a transmitter of any ERP on the other side, at any time of day or season, on any frequency. This report gives a description of the measuring programme, and an analysis of the results obtained.

3. EQUIPMENT AND METHOD OF MAKING THE MEASUREMENTS.

The receiver was a Type AR - 88 D with a vertical aerial 10 metres long. The receiver is calibrated in terms of input microvolts at 1 Mc/s against the receiver "S" meter (rectified carrier current) reading, and also in terms of a constant RF voltage at frequencies in steps of 0·5 Mc/s throughout the tuning range, this calibration also being with reference to the "S" meter reading. From the two graphs thus prepared the input RF voltage to the receiver corresponding with an "S" meter reading can be read off at any tuned frequency. A conversion factor in db that takes account of the effective height of the aerial, and the feeder and coupling equivalents, has been determined from a large series of comparison field strength measurements made with commercially-designed field-strength measurement apparatus. By further comparison checks with the two sets of apparatus, it has been found that the divergence between the measurements obtained by one method and those by the other never exceeds 4 db, and is generally within 2 db, provided that the receiver meter zero (i.e. zero signal reading) is frequently checked, and that the receiver is operated at a closely constant supply voltage. During the programme of measurements of WWV it was ensured that all these precautions were observed, the apparatus being operated only by senior staff, special maintenance being given, and gain/noise factor checks made frequently.

The measurements were made hourly, as near as possible to the hour, from 0800 through midnight to 0300 GMT. It was not practicable to make measurements during the hours 0400 to 0700 GMT inclusive. In making a measurement the engineers observed the peak signal value, and obtained the average value of this over several fading cycles, this being the value given. It was considered that any attempt to read the mean or median field-strength over a fading cycle would lead to inaccuracy, and be more liable to subjective errors than the reading of the average of the peak values. Only by recording and subsequent analysis could the true mean value have been determined. The values used in this report are therefore mean-peak values, and are assumed to correspond approximately to upper-decile values of field-strength, i.e. values exceeded for 10% of the total time. The highest values of field-strength observed were of the order of 700 µV/m on 5 Mc/s, the values on the higher frequencies being, generally speaking, much lower than this. Many readings were, of course, for zero field, and these have been included in the analysis.

4. CORRECTIONS TO THE MEASUREMENTS.

4.1. Mode of Transmission.

It was desired to convert the figures thus obtained into decibels referred to 1 µV/m, reduced to a constant transmitted power. This is necessary in order to compare in the same terms propagation conditions upon the different transmitting frequencies, and to interpolate the field-strengths for intermediate frequencies.

It has been reported before[1] that there is a relation between the frequency and the mode of propagation across the Atlantic, implying that the transmitting and arrival angles in the vertical plane would vary with frequency. If this be so it is necessary to correct the measured values in accordance with the radiation pattern of the transmitting aerials, in order to make allowance for the different ERP at different vertical angles. (No correction to the power fed to the aerials was necessary in order to take account of azimuthal directivity, because the aerials are vertical dipoles and therefore the pattern is omnidirectional.)

Reference (1) indicates that there is a simple relation between the frequency and the mode of transmission, but it was felt that, in practice, the latter must vary, for any frequency, with time of day and season, as well as with the sunspot cycle. Accordingly, since the matter appeared to be complex, it was given further study.

The Engineering Department of the Post Office have obtained information on wave-arrival angles (and thus on the modes of propagation) for the circuit from Lawrenceville, New Jersey, to their receiving station at Cooling, by measurements made on the MUSA apparatus. From a study of these angles the following general principles were established. On the higher frequencies the tendency is for transmission to be by the least possible number of hops having regard to the geometry of the wave path. This is because the ionisation will not, generally speaking, sustain transmission on these frequencies at the higher angles. With decreasing frequency the tendency is for the mode order to increase, because the ionisation can sustain such transmission at the lower frequencies. When the ionisation rapidly increases (as during the early morning), there is a sharp change in the mode of transmission. The lower mode orders tend to disappear because they are cut off by the failure of the wave to penetrate the E layer at the lower angles as its ionisation increases, and this effect is more apparent the lower the frequency. Thus on the lower frequencies only a higher mode order can traverse the circuit. In the evening the situation reverts relatively quickly to the pre-sunrise conditions. For a similar reason there is a tendency for the mode order to increase in summer and with increasing sunspot activity, because under both these conditions the ionisation of the E layer increases.

Summarising, it is clear that the tendency is for the mode order to increase with decreasing frequency and with increasing ionisation of the E layer. Thus, for a circuit of given length, there will be more hops the lower the frequency, more hops by day than by night, in summer than in winter, and towards sunspot maximum than towards sunspot minimum.

A study of the measured angles obtained by the Post Office for years near sunspot minimum enabled the modes of transmission to be worked out for the Washington/Tatsfield circuit (which is not very different from the circuit Lawrenceville/Cooling for which the measurements are given). In establishing the mode of transmission there is a further complexity in the fact that the heights of reflection vary from night to day and from summer to winter. Nevertheless, by making allowance for this, the modes of transmission for the various frequencies, times of day and seasons were obtained in terms of the predominant wave angles, it being assumed that the departure angle and the arrival angle are equal. The data are given in Fig. 1(a) and in Table I, Columns 2 and 3.

4.2. Transmitting and Receiving Aerials.

WWV uses vertical half-wave aerials for each transmitting frequency and, in order to assess the allowance to be made for the ERP at different vertical angles, the radiation diagram of such aerials was examined. The relevant information was obtained from the American Radio Propagation Unit Document No. 2,[2] in the section "Sky-Wave Radiated Power versus Frequency for Grounded Vertical Antennas over Good Ground". Fig. 1(b) gives the ERP obtained for such aerials at various angles on various frequencies, in db referred to 1 kW fed to the aerial. The loss due to the aerial, compared to 1 kW, at the appropriate angles corresponding to the modes of transmission prevailing for different frequencies, times of day and seasons, is given in Table I, Column 4.

Because of the nature of the equipment used and the method of making the measurements at Tatsfield (details of which have been given in Section 3), it was not necessary to make any correction in order to take account of the vertical pattern of the receiving aerial.

4.3. Power Correction and Total Correction.

The power fed to the aerials at WWV was approximately 8 kW on 5, 10 and 15 Mc/s, and approximately 1 kW on 20 Mc/s (except during the period 1st July to 4th August, when it was approximately 8 kW on 20 Mc/s). The power gains in db referred to 1 kW for the various frequencies are therefore those shown in Table I, Column 5.

TABLE I

	Frequency Mc/s	Mode of Transmission	Predominant Wave Angle	Trans. Aerial Loss db/1 kW	Power Gain db/1 kW	Total Correction db/1 µV/m
WINTER NIGHT	20	2 hop	5°	– 11	0	+ 11
	15	2 hop	5°	– 10	+ 9	+ 1
	10	2 hop	5°	– 10	+ 9	+ 1
	5	3 hop	13°	– 5	+ 9	– 4
WINTER DAY	20	2 hop	5°	– 11	0	+ 11
	15	2 hop	5°	– 10	+ 9	+ 1
	10	3 hop	11°	– 6	+ 9	– 3
	5	4 hop	18°	– 4	+ 9	– 5
SUMMER NIGHT	20	2 hop	5°	– 11	0(1)	+ 11(2)
	15	2 hop	5°	– 10	+ 9	+ 1
	10	3 hop	13°	– 6	+ 9	– 3
	5	4 hop	20°	– 4	+ 9	– 5
SUMMER DAY	20	2 hop	7°	– 9	0(1)	+ 9(3)
	15	3 hop	15°	– 6	+ 9	– 3
	10	4 hop	23°	– 6	+ 9	– 3
	5	5 hop	29°	– 6	+ 9	– 3

(1) 1st July to 4th August = + 9 db.
(2) 1st July to 4th August = + 2 db.
(3) 1st July to 4th August = 0 db.

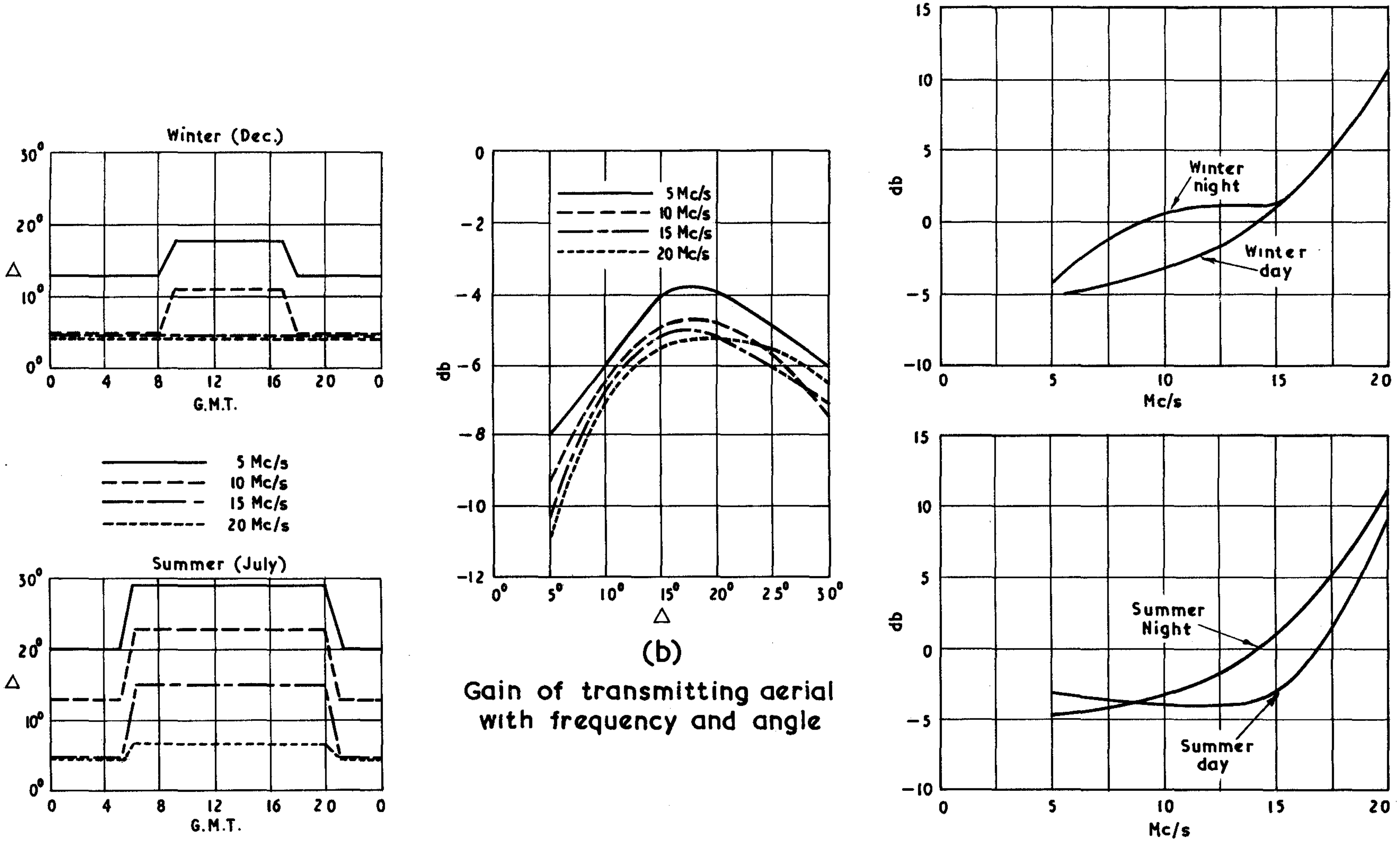
The total correction to be applied to the measurements, in db referred to 1 μV/m, in order to take account of mode of transmission at various times of day and seasons, vertical pattern of the transmitting aerials and differences in power fed to the aerial, are shown in Fig. 1(c), and in Table I, Column 6, these latter being, of course, the algebraic sum of the values shown in Columns 4 and 5, with the sign reversed.

5. METHOD OF ANALYSIS.

In order to analyse the measurements the monthly mean of these was obtained for each hour of day, and in this operation all the measurements including those for zero field were taken, but all measurements which were doubtful due to interference or any other cause were excluded. The monthly mean for each hour so obtained may be regarded as the monthly mean of the mean-peak field, and in order for it to be reliable 10 values were considered as the minimum necessary (excluding zero values). If only 4 or less values were available (excluding zero values) no mean was taken, and if only from 5 to 9 values were available the mean was regarded as being doubtful, was placed in brackets, and was not necessarily adhered to.

The mean values of field-strength were then converted into decibels referred to 1 μV/m, and the correction for each frequency, time of day and season shown in Table I, Column 6, was applied to them. In applying the corrections due account was taken of the difference in time along the transmission path, and also of the changes in sunrise and sunset times from month to month.

The corrected values were then plotted on graph paper on a scale of frequency against time of day, for each particular month, in order that the distribution of the field might be ascertained on a frequency/time basis. Since it was desired to compare the received field with the MUF predictions for the circuit there was also drawn upon each graph the predicted MUF for each month for the Washington/Tatsfield transmission path, as obtained from the appropriate DSIR monthly MUF chart, this being the W zone chart for both ends of the circuit. An example of such a set of corrected measurements plotted upon the graph of predicted MUF is shown in Fig. 2, in which the predicted MUF is shown as a dashed line. It was also desired to compare the received field with the predicted LUF, if only to explain the weakness or complete absence of field on the lower frequencies during daylight hours. The LUF for a circuit is the frequency below which communication will be unsatisfactory because of the combined effects of ionospheric absorption and atmospheric noise, having regard to the ERP and the type of communication it is desired to effect. The values of absorption and noise were obtained from the usual CRPL data, and, since the field was to be plotted for a constant transmitted power of 1 kW the LUF was also calculated for an ERP of 1 kW. The type of communication provided by WWV is, of course, a Standard Frequency service, and, so far as is known, the required field-strength for intelligible reception of such a service has never been assessed. The reference level for the field-strengths required for the intelligible reception of various types of service is that for double sideband radiotelephony with 100% modulation, and that for modulated CW manual telegraphy with 100% modulation is 15 decibels below this. Though the transmissions of WWV consist largely of CW modulated with tone or manual telegraphy they would appear to have a higher requirement for intelligible reception than ordinary modulated CW manual telegraphy, though certainly considerably below that for double sideband



(a)
Predominant wave-angles

(b)
Gain of transmitting aerial with frequency and angle

(c)
Correction factor for mode of transmission and E.R.P.

Fig. 1

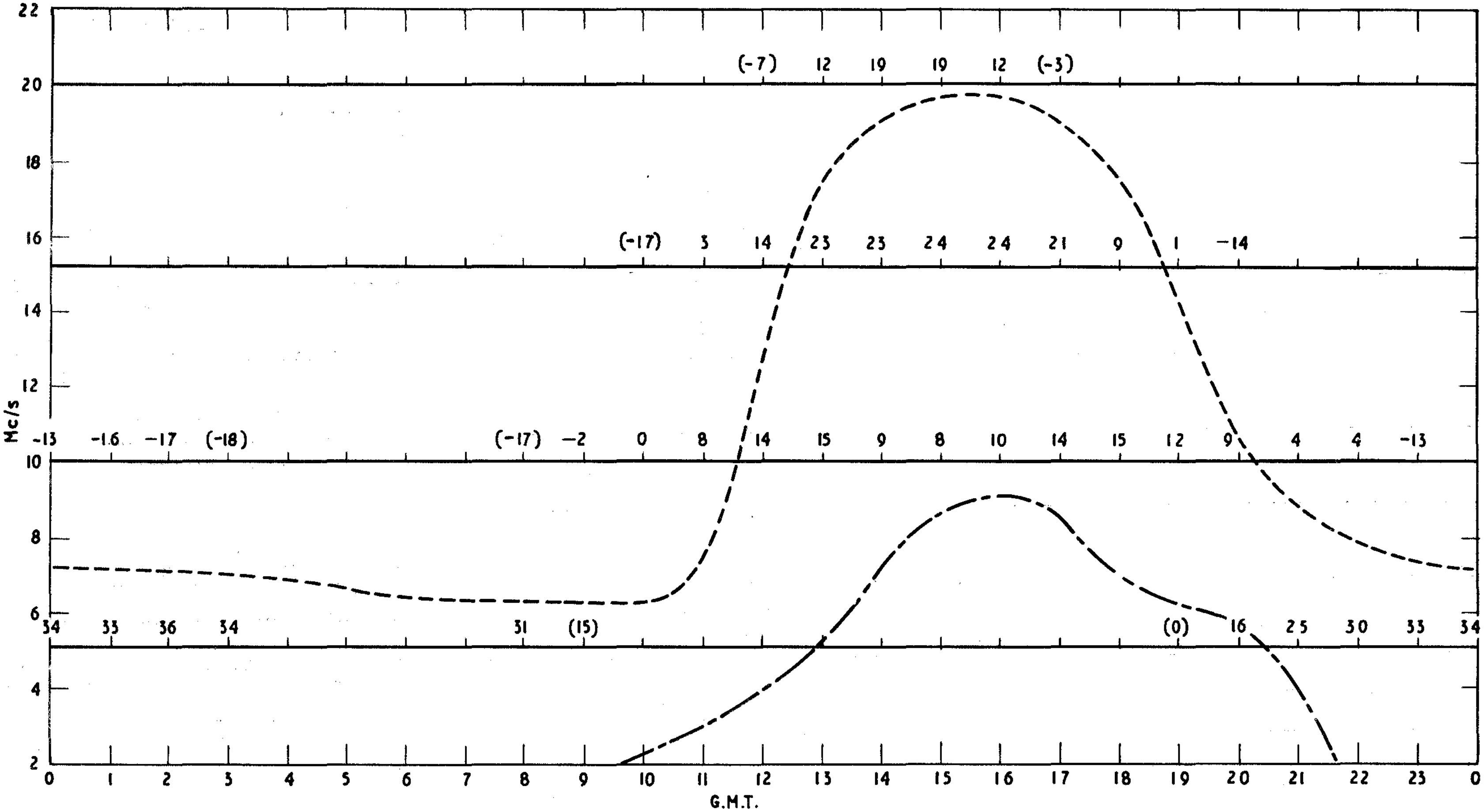


Fig. 2

Example of a set of corrected mean field-strength values, these being for December 1953.

radiotelephony. It was estimated for the purposes of this report, that the field-strength necessary for the intelligible reception of the WWV transmissions would be about 9 decibels below that required for double sideband radiotelephony, and the LUF, which is shown in Fig. 2 as a dot-dashed line, is that calculated for this requirement. It may be added that, since the main aim is to show the field distribution with frequency and time and not to show the intelligibility of reception for any particular service, the LUF curve is only required as a useful guide as to the frequency on which the field decays due to absorption.

Having plotted the monthly mean values of field-strength as in Fig. 2, it was then possible to connect values of equal field strength by drawing in the contours corresponding to chosen decibel values (generally in steps of 10 db), and so to interpolate the field-strength values for all frequencies and times of day. The results are given, for each month, in Figs. 3 to 8, which therefore show the contours of the mean monthly mean-peak field on a frequency/time basis.

It was considered that the contours should be plotted in the same terms as those in which the measurements were made, and which are regarded to be those of the field which would be exceeded for 10% of the time. It has been shown,[3, 4] that fading signals of the kind measured have a log-normal amplitude distribution, for which the ratio of the level exceeded 10% of the time to the median level is 7 db. This takes account of the short period fading, but there is a further day-to-day fluctuation in the amplitudes of short-wave signals, which, however, is taken account of by the process of taking monthly mean values of field-strength for each hour. In comparing the contours with the MUF and LUF curves, therefore, it should be considered that the median value of the field is 7 db below the values plotted, i.e. that a monthly mean value of median field of 0 db is equivalent to a value of 7 db in the field contours shown.

6. DISCUSSION OF RESULTS.

6.1. General Study of the Field.

Figs. 3 to 8 indicate that, to a first approximation, the field is distributed, with frequency and with time, somewhat as the predictions indicate, and that the frequency variations in its distribution from month-to-month are also approximately similar to those predicted. There is, for example, a striking difference in the field distributions as between July and December, as there is also a striking difference in the shape of the predicted MUF and LUF curves for those two months.

The field is, in general, very much stronger at night than during the day, particularly in summer, a fact which may be explained as follows. Although there is one predominant mode of propagation, it is possible at times for there to be several mode orders present simultaneously, each contributing to the total field. During the daytime in July the E layer ionisation is at its highest, and transmission of the lower mode orders is cut off, whilst, the F_2 layer ionisation being relatively low, propagation of the higher mode orders is not possible (Fig. 3). Reception is, therefore, probably by a single mode which, the absorption being at its highest, is itself heavily absorbed, and the result is a very weak field. During the night in July the E layer cut-off frequency is, of course, very low and transmission of the lower mode orders is possible, but, in addition to these, there may be several higher mode orders contributing to the field at the same time, provided the ionisation is high enough to sustain their propagation. The absorption is also at a very low value and the result is a high field-strength. The night-time field decreases somewhat from July towards December (Fig. 8), probably owing to the fact that, towards winter, propagation of some of the higher mode orders can no longer be sustained because of the decreasing ionisation. The daytime field, however, increases considerably from July towards December, because of the considerable decrease in the daytime absorption and in the E layer cut-off frequency. This permits of propagation of lower mode orders, whilst at the same time propagation of the higher mode orders is also possible. The reception of several simultaneous modes of transmission during the winter daytime thus results in a higher field.

As regards the distribution of the field with frequency it would appear that at 0300 GMT in July (Fig. 3) (when the absorption has its lowest diurnal value) the field increases from the 10 db value at about 3 Mc/s to the 40 db value at about 4·5 Mc/s, decreasing again from the 40 db value at about 8 Mc/s to the 10 db value at about 13 Mc/s. It would seem, therefore, that the area of highest field covers frequencies very considerably below those at which propagation fails because of electron limitation. This would seem to be in conformity with the considerations mentioned in the last paragraph, because it is only at such lower frequencies that propagation of the higher mode orders can be sustained. It does not, however, agree with an old established rule which says that best reception should be obtained *just* below the MUF. Provided the absorption is low the highest field will occur on frequencies *considerably* below, and will extend to those *far* below, the MUF. The term "Optimum Working Frequency", as now generally used for a frequency precisely 15% below the median MUF, would thus appear to be a misnomer. From July towards December (Fig. 8) the decreasing night-time ionisation results in the 10 db value of field decreasing to lower and lower frequencies, though the area of highest field still extends considerably below the highest frequencies propagated. At the same time the areas of high field extend to later and later hours of day, due to the later time of sunrise over the path, and the later time of the increase in the absorption.

The daytime field in July (Fig. 3), when the absorption is at its highest value, appears to be very low, due probably to the propagation of only a single mode and to the fact that even that may be considerably attenuated by absorption. The area of highest field appears to be restricted to a narrow band between about 13 and 15 Mc/s, because of the high absorption and the relatively low ionisation of the F_2 layer. Furthermore this band is only slightly below the highest frequency propagated, as would be expected if it were due to a single mode. Only towards evening, when the absorption decreases, does the field increase to the 20 db level. Conditions are much the same during August (Fig. 4), but in September (Fig. 5) there begins to appear a change in the shape of the daytime contours, due to the increasing F_2 layer ionisation and decreasing absorption. By October (Fig. 6) the daytime distribution of the field has altered considerably, the 10 db area now extending from about 22 to 14 Mc/s, and, furthermore, the field appears to exceed 20 db on the higher frequencies. This augmentation process of the daytime field appears to continue towards December (Fig. 8), by which month the 10 db level of field appears to extend from about 22 to 10 Mc/s, and the 20 db level to cover a wide frequency/time area. Though the area of high field is, in December, extended far towards the high frequencies as compared with July, yet on the lower frequencies (i.e. 14 Mc/s) the field is also stronger in December than in July. In fact the point of highest field may lie on a lower

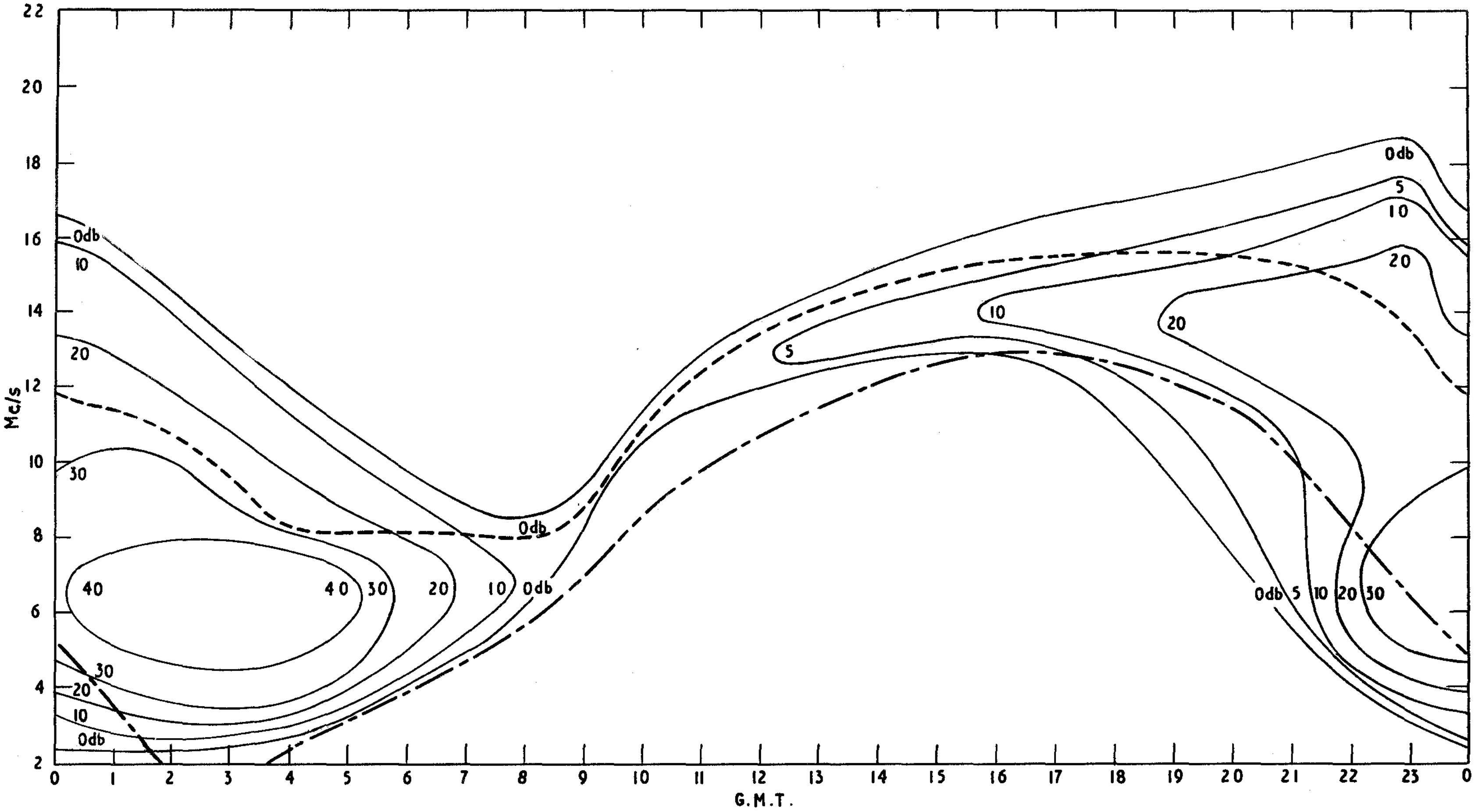


Fig.3

Field-strength contours for July 1953

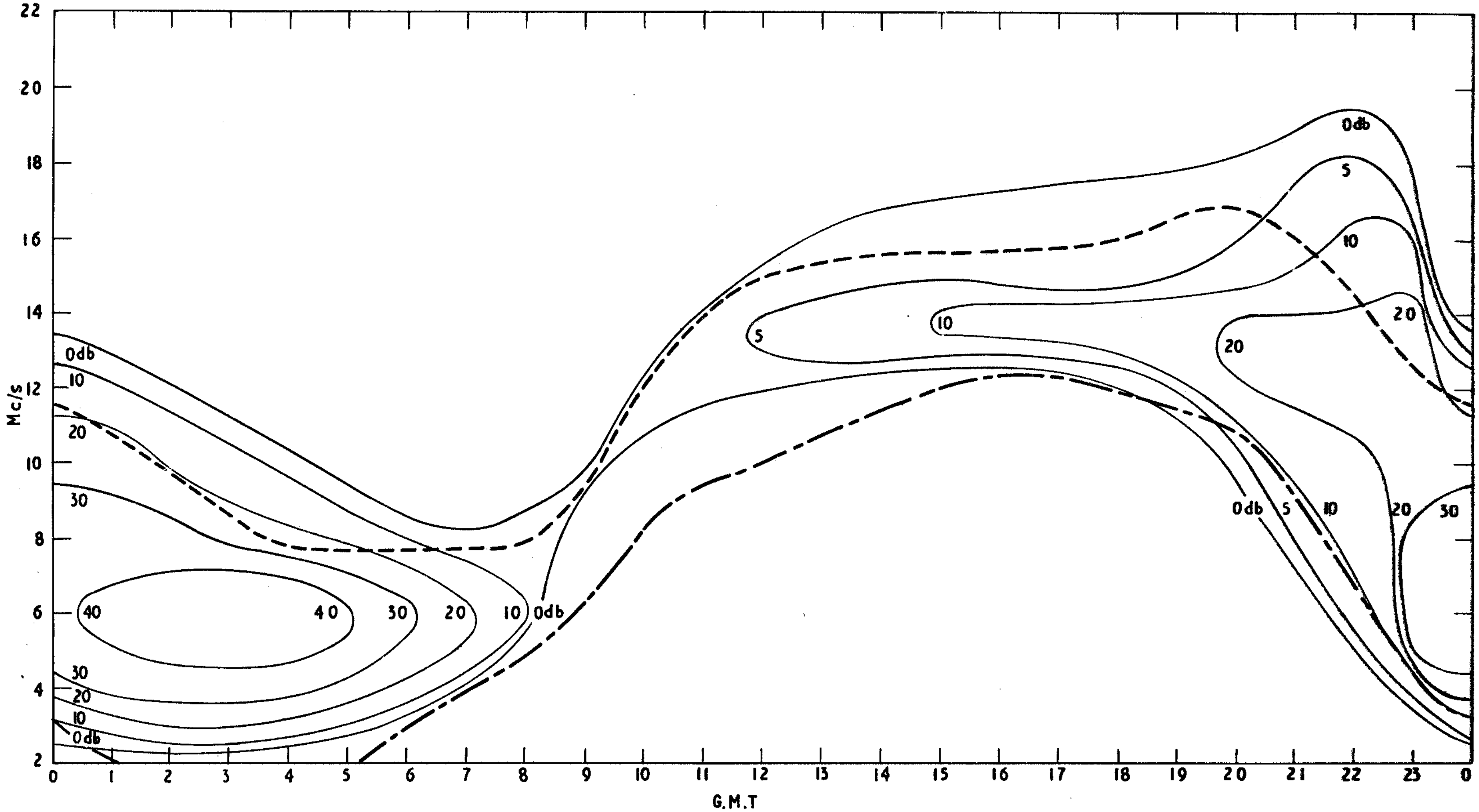


Fig.4

Field-strength contours for August 1953

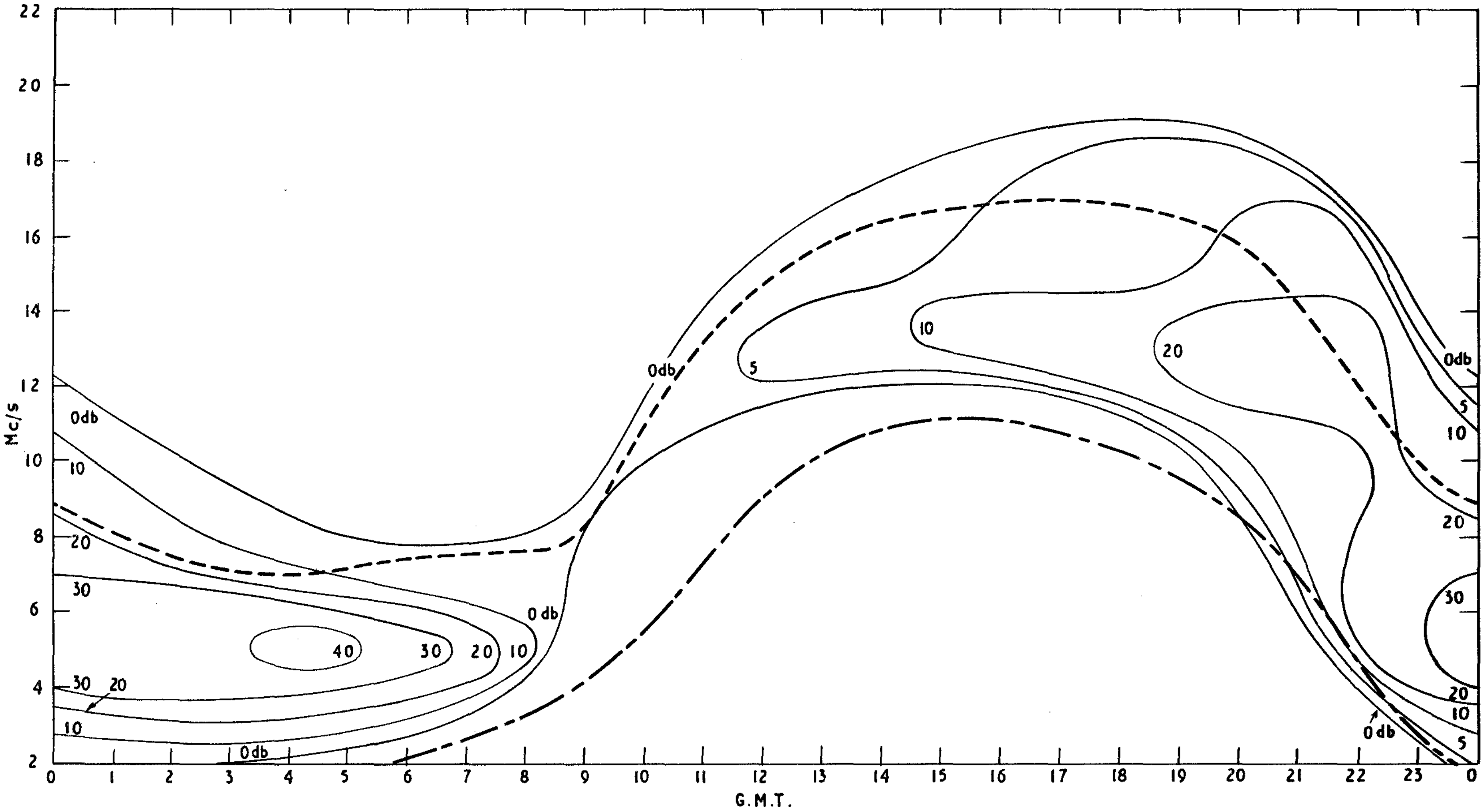


Fig. 5

Field-strength contours for September 1953

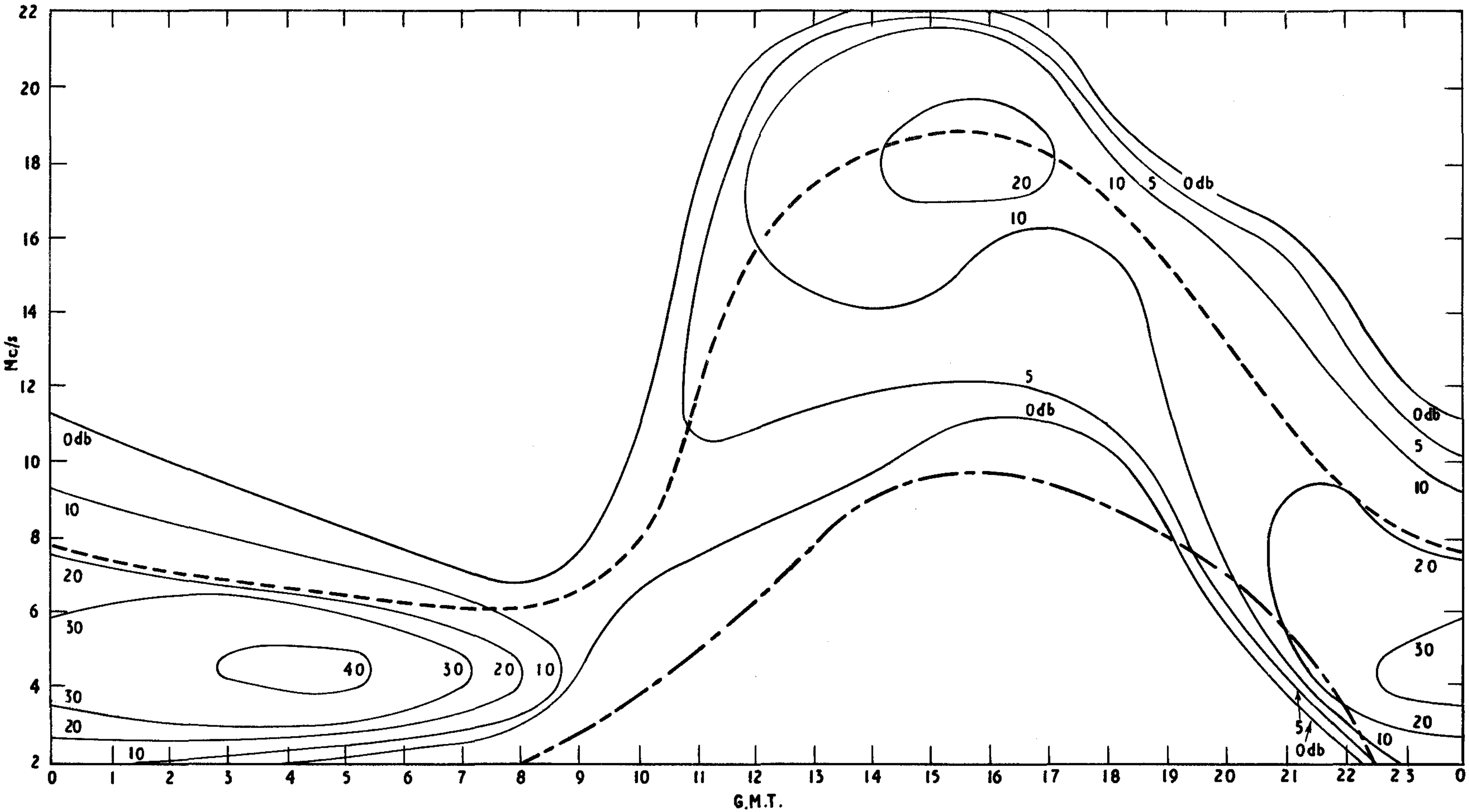


Fig.6

Field-strength contours for October 1953

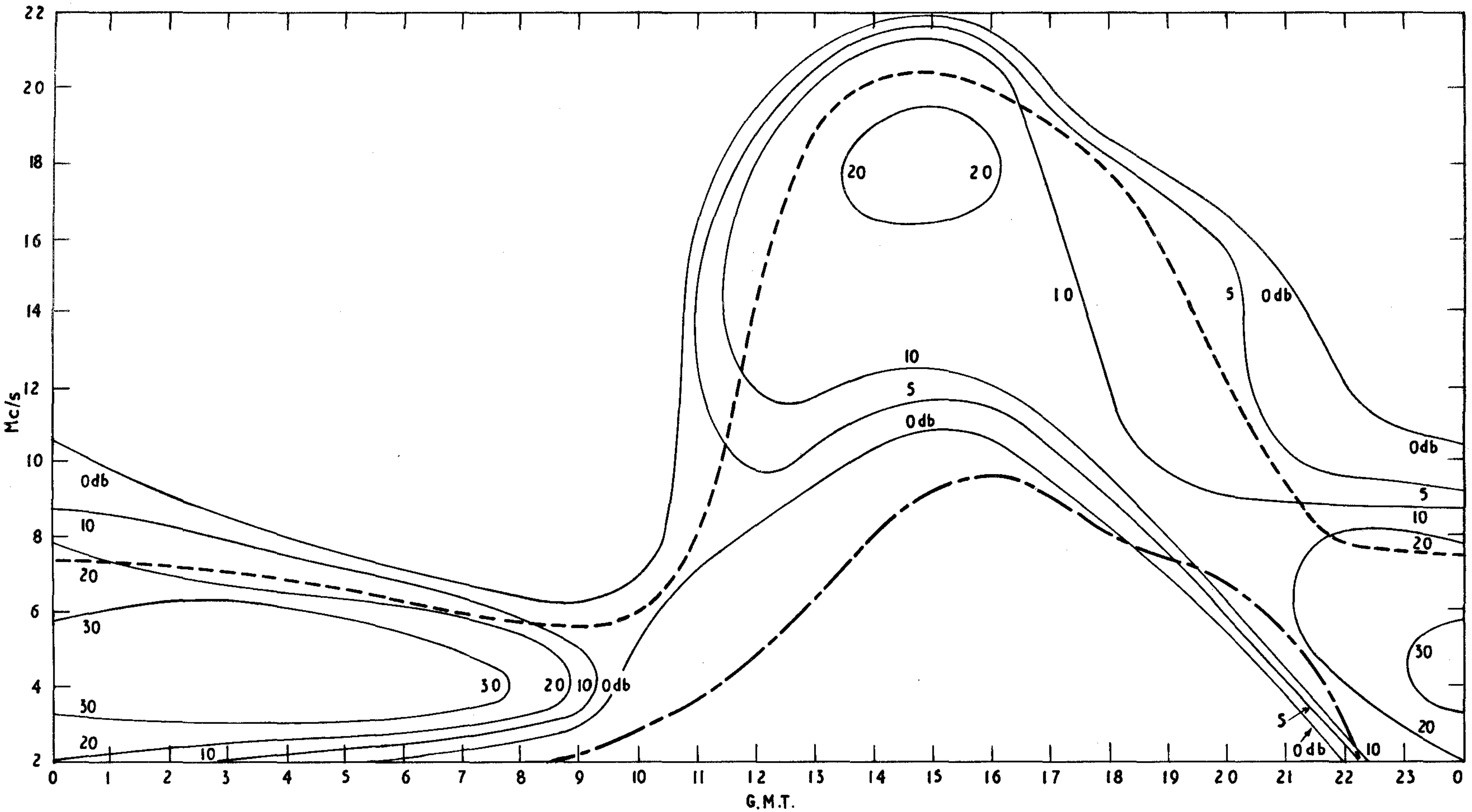


Fig.7

Field-strength contours for November 1953

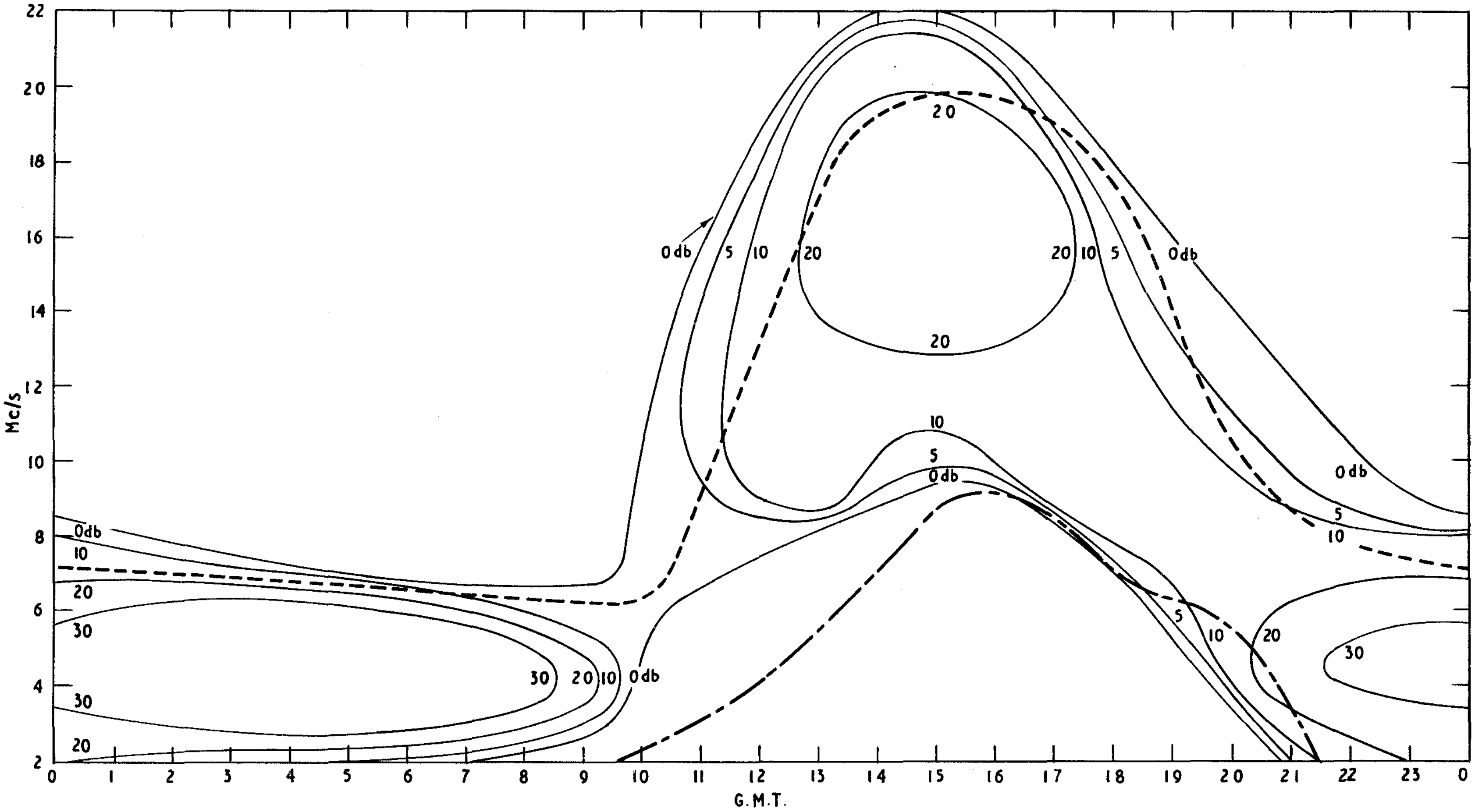


Fig. 8

Field-strength contours for December 1953 frequency in December than in July. As in the case of the night-time field, the area of highest field strength appears, during the winter months, to lie *considerably* below the highest frequencies propagated, and to extend to progressively lower frequencies as winter advances. The general shift of stronger fields towards the higher frequencies towards winter is in conformity with the increase in ionisation of the F_2 layer towards that season, while the general strengthening of the daytime field and the extension of the high-field areas towards lower frequencies is due to the decrease in absorption, and in the E layer cut-off frequency, leading to the propagation of several simultaneous modes of transmission. The high evening fields are seen to occur on lower and lower frequencies as winter advances, which is in conformity with the earlier sunset times and the consequent decrease in ionisation of the F_2 layer during the evening hours.

6.2. Comparison of the Field with Predicted MUF.

The general shape of the field-strength contours, and the change in this shape from July towards December, corresponds fairly well with those of the MUF curves. The night-time field-strength contours for July indicate that the predicted MUF is far too low, but this effect becomes less marked with each succeeding month, so that, in the latter months of the year the night-time contours disagree only very slightly with the MUF predictions. During daytime in July the contours follow the predicted MUF (albeit they indicate low fields) until around sunset, when the indications are that there is an increase in the usable frequencies which is not shown by the predictions. An increase in field-strength just before fade-out is, however, well known in practice.

During the remaining months of the year there is a tendency for the MUF predictions to be low in frequency, particularly over the main daytime period, as judged by the field-strength contours. Similarly the contours indicate that, for any particular frequency, the monthly mean time of fade-in is somewhat earlier, and that of fade-out is somewhat later, than is shown by the MUF prediction. The general change of shape of the MUF curve from month to month is, however, confirmed by the field-strength contours, and, furthermore, the areas of highest field-strength are, both by night and by day, generally below the predicted MUF.

Summing up, it may be said that the MUF predictions do indicate fairly well, for each month, the frequencies above which the field tends to become weak, there being a tendency for them to be low in frequency at certain times of day and season. The frequency/time areas of strongest field are, however, usually to be found below the predicted MUF.

6.3. Comparison of the Field with Predicted LUF.

One of the most striking features of the field-strength contours is that they indicate that during the forenoon period when, according to the MUF and LUF predictions, a strong field should be present on certain of the lower frequencies (4 to 12 Mc/s varying with the season), no such field is observed. Thus in September (Fig. 5), for example, there seems to be no reason why a strong field should not be received on 10 Mc/s from 0930 to 1300 GMT. It will be observed that, by December, a considerably field *is* measured on 10 Mc/s, but that it is then unaccountably absent on 5 Mc/s. It would appear that the reason for this forenoon period of no field must be that the LUF is, at this time, much higher than is predicted, and in fact, approaches the MUF, so that the field is very weak on the relevant frequencies during all months. On the other hand the indications are that, towards evening, the LUF must decrease to low values considerably earlier than is predicted, for the contours indicate an increasing field on frequencies well below the LUF. If the LUF were based entirely upon the absorption then the curve would decrease to low frequency values at much the same time as the contours suggest. But the LUF is partly dependent on the value of atmospheric noise at the receiver, and such noise has a higher value towards local evening hours. Thus the LUF has a higher evening value than if it were dependent upon absorption alone. This discrepancy between the predicted LUF and the field-strength contours might therefore be due to the fact that the evening noise level at Tatsfield is lower than is assumed in the calculation of the LUF. On the other hand, having regard to the character of the measurements, one would hardly expect the field-strength contours to coincide exactly with the LUF curve.

Apart from these two discrepancies the predicted LUF curve, does, in fact, give a good indication of the frequencies below which, month by month, the field will be weak due to absorption. It explains the weakness or complete absence of field on the lower frequencies during the daytime period, its seasonal decrease in frequency from July to December seems to be well borne out, and there is good evidence, from the shape of the contours around 10 Mc/s during October, November and December that the peak due to the absorption does occur about the time and on the frequencies indicated.

7. CONCLUSIONS.

a. To a first approximation the field is distributed, with frequency and with time, somewhat as the MUF and LUF predictions indicate, and the large frequency variations in its distribution from month to month are also approximately as indicated by the predictions.

b. The frequency/time areas of highest field occur where multiple modes of transmission are possible, and they thus occur *considerably* below the actual MUF. Near the MUF the higher mode orders are not propagated, and on the lower frequencies the lower mode orders are cut off or the energy is absorbed, weak fields resulting in both cases.

c. Due to these considerations the night-time field is much stronger than the daytime field, and it tends to decrease somewhat in strength from summer to winter because of the decrease in night-time F_2 layer ionisation.

d. Due to the considerations of (b) the daytime field is particularly weak in summer, and it increases considerably in strength from summer to winter because of the decrease in absorption and in the E layer cut-off frequency, and of the increase in daytime F_2 layer ionisation.

e. The high night-time fields extend to lower frequencies and more hours of day from summer to winter because of the winter decrease in absorption.

f. The high daytime fields extend to much higher frequencies in winter than in summer, because of the winter daytime increase in F_2 layer ionisation. At the same time the high fields in winter extend to frequencies far below the MUF, and, on the lower frequencies the field is still stronger in winter than in summer, because of the winter decrease in absorption and in E layer cut-off frequency.

g. The predicted MUF has a tendency to be low in frequency during certain times of day and season, the predicted fade-in times to be too late and the fade-out times to be too early. But the areas of highest field are usually to be found below the predicted MUF.

h. During the forenoon period there is, during all months, a period of very weak field which is not accounted for by the predicted LUF. During the daily period of high absorption the predicted LUF appears to be substantially correct, but during the evening period it appears to be too high in frequency. However this latter discrepancy may be due to the effects of atmospheric noise.

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9. REFERENCES.

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3. C.C.I.R. VIIth Plenary Assembly, London 1953, *Doc. 780*, p.7, Note (a).

4. C.C.I.R. VIIth Plenary Assembly, London 1953, *Doc. 777*, p.3, General Note.